EARLY PROSPECTS FOR ELECTROWEAK PHYSICS IN CMS

5/19/10

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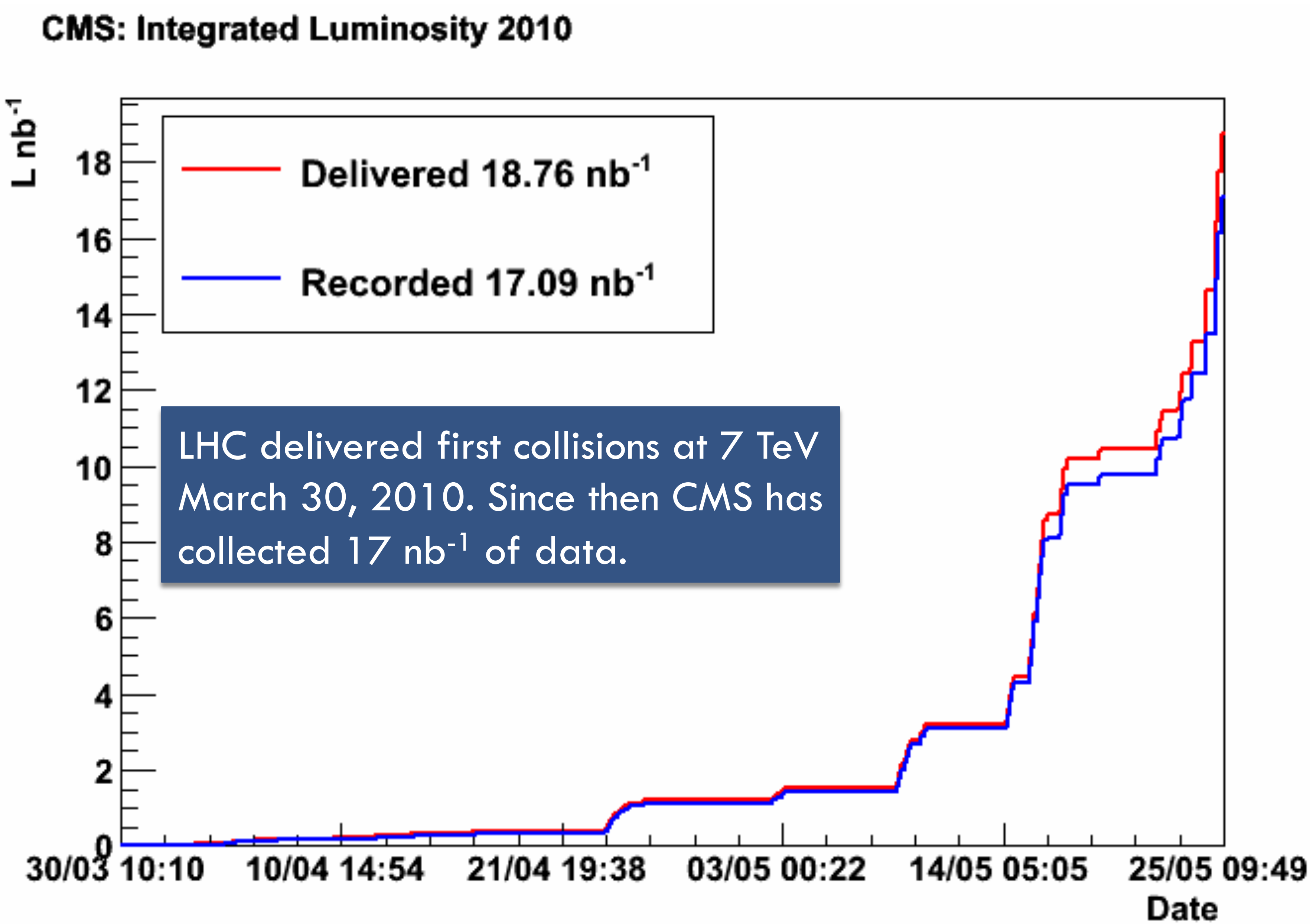
Overview

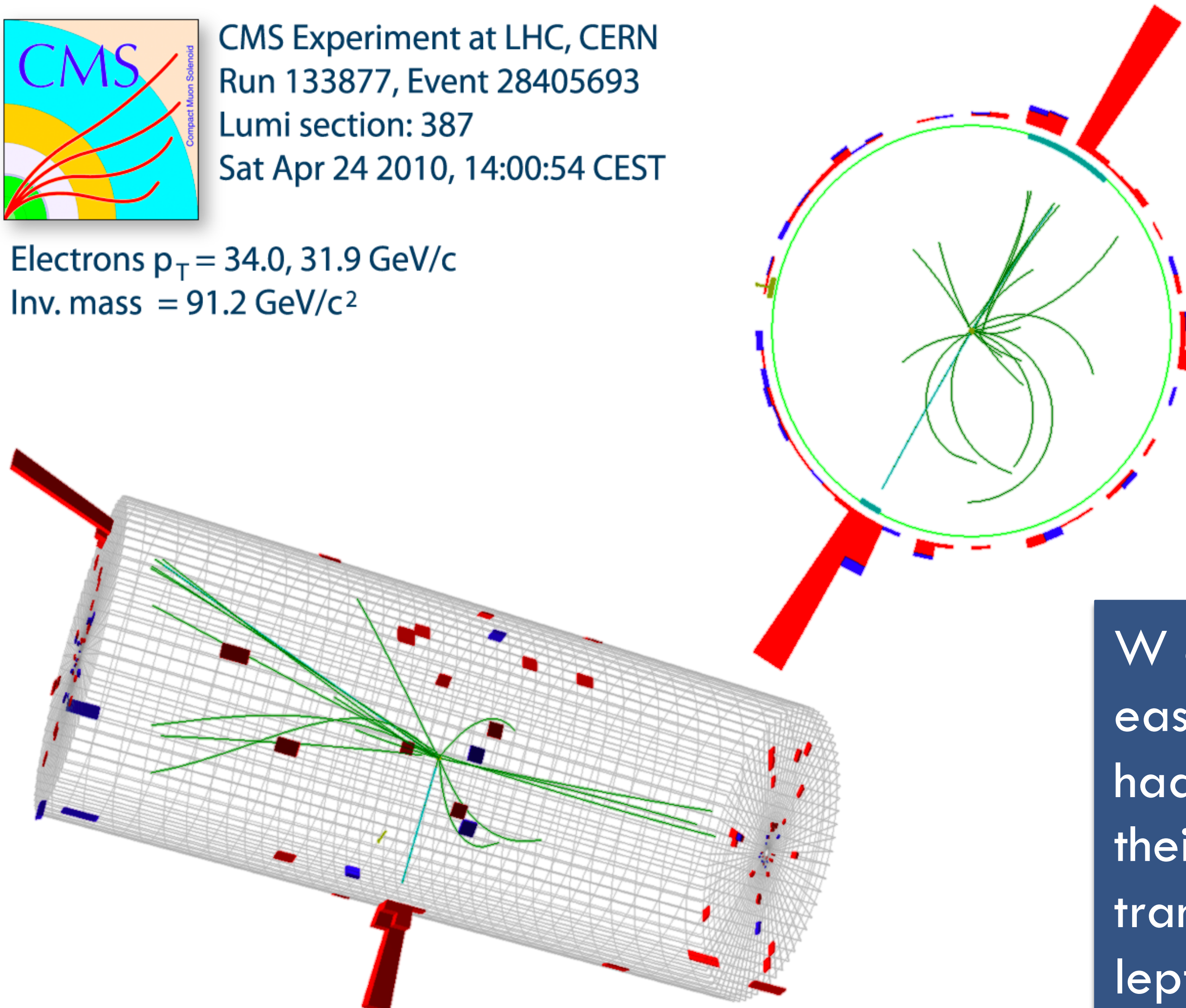
- Electroweak physics at the LHC
- The CMS Experiment
- Inclusive W & Z Cross-Section Measurements
- Z Differential Cross-Section Measurements
- W Charge Asymmetry
- Jet Production in Association with W's & Z's

Electroweak Physics at the LHC



LHC delivered first collisions at 7 TeV March 30, 2010. Since then CMS has collected 17 nb^{-1} of data.

Electroweak Physics at the LHC



CMS $Z \rightarrow e^+e^-$ Candidate Event

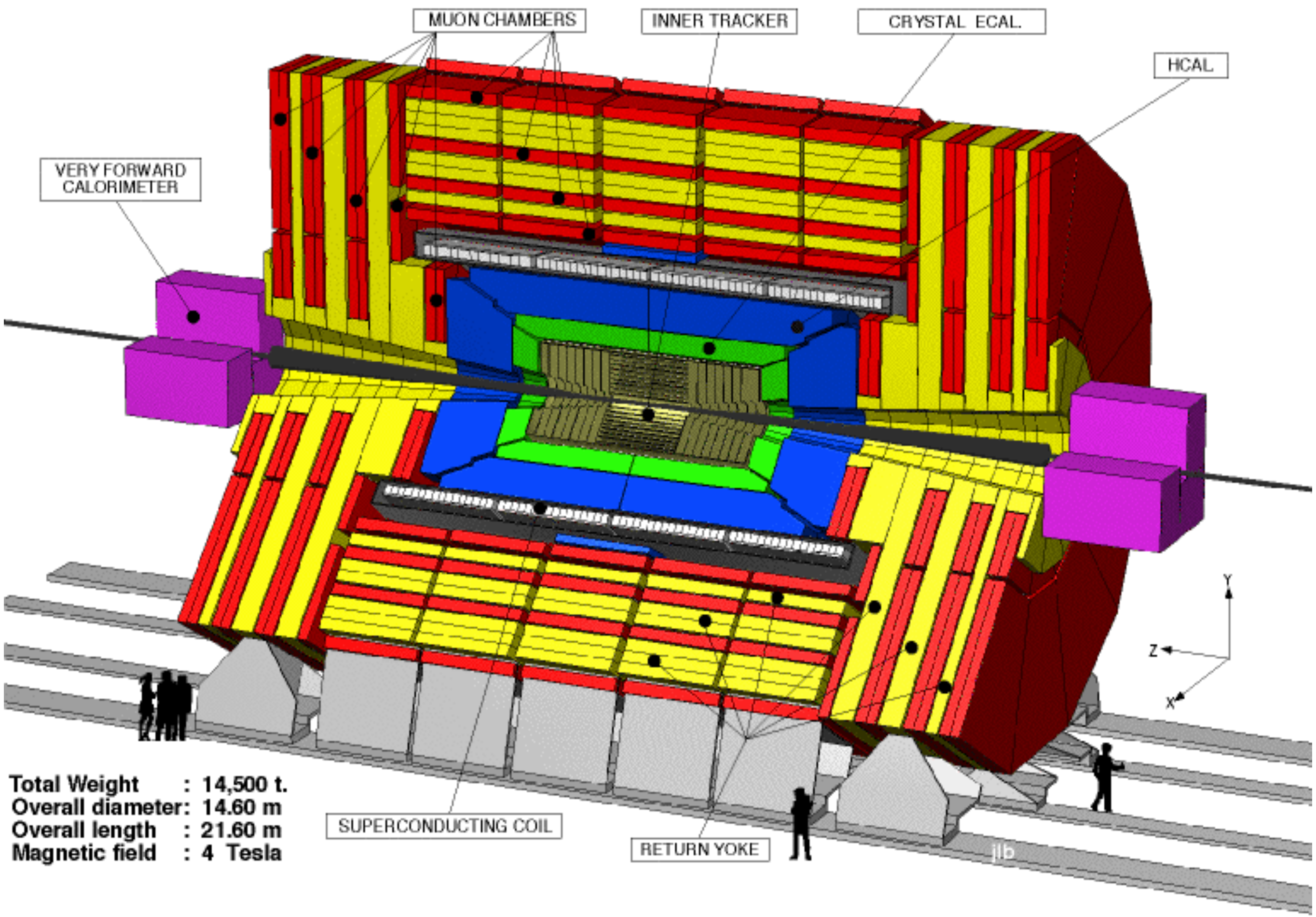
W & Z boson decays are easily identified in the hadronic environment via their signature high transverse momentum leptons.

Electroweak Physics at the LHC

- Leptonic decays of W and Z bosons allow for clean experimental measurement of their production rates.
- Will be among the first physics results at LHC.
  - Expect ~20 W candidates per nb^{-1}
  - Expect ~2 Z candidates per nb^{-1} ($M_Z > 40$ GeV/c^2)
- Important for commissioning CMS and understanding lepton detection in early data.
- With increased statistics can cross-check theoretical cross-section predictions, PDF accuracy, etc. in a new energy regime.

The Compact Muon Solenoid (CMS)

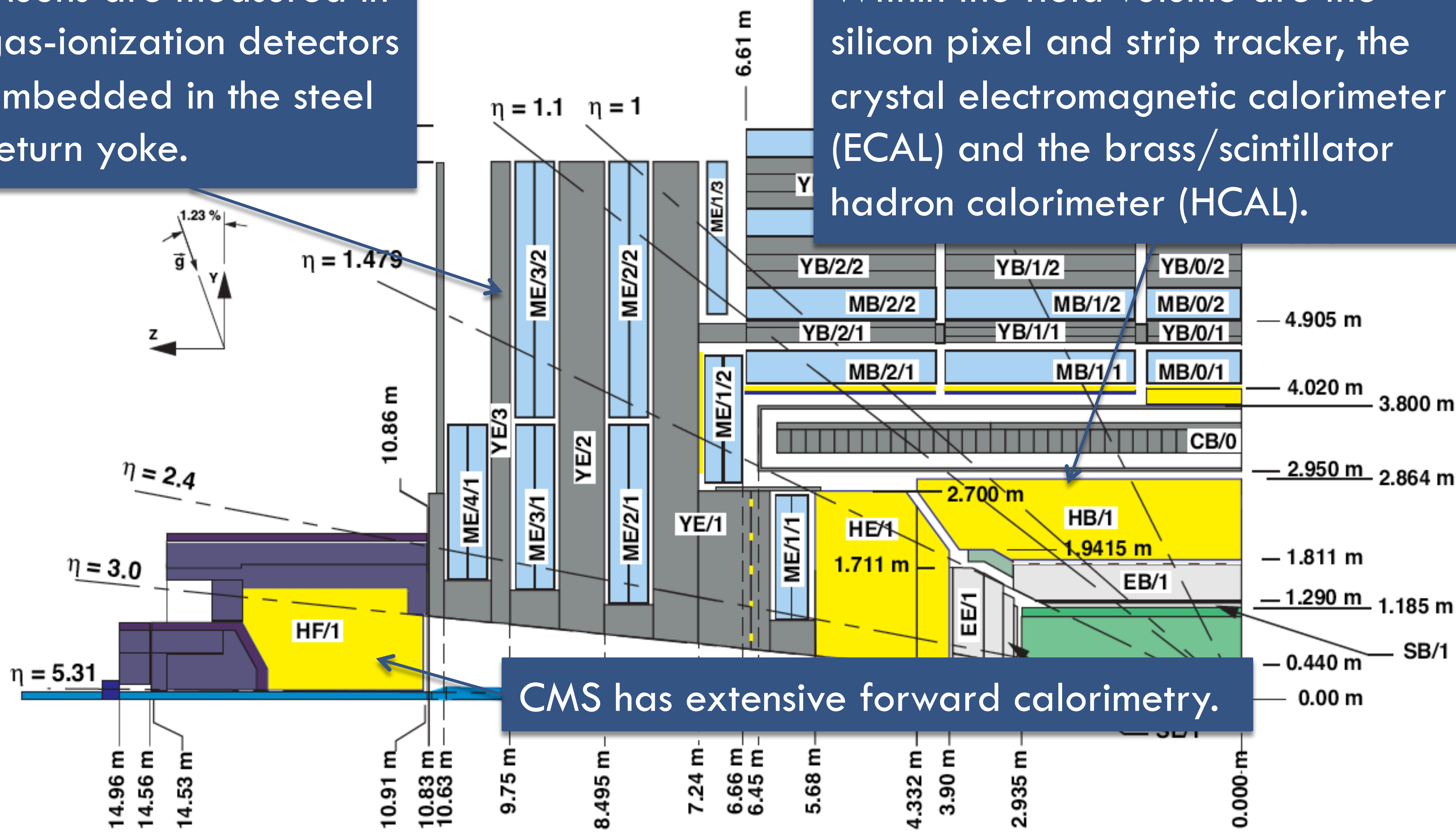
Central feature of the CMS detector is a superconducting solenoid, of 6m internal diameter, providing a field of 3.8T.



The Compact Muon Solenoid (CMS)

Muons are measured in gas-ionization detectors embedded in the steel return yoke.

Within the field volume are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter (ECAL) and the brass/scintillator hadron calorimeter (HCAL).



CMS has extensive forward calorimetry.

Inclusive W & Z Cross-Sections

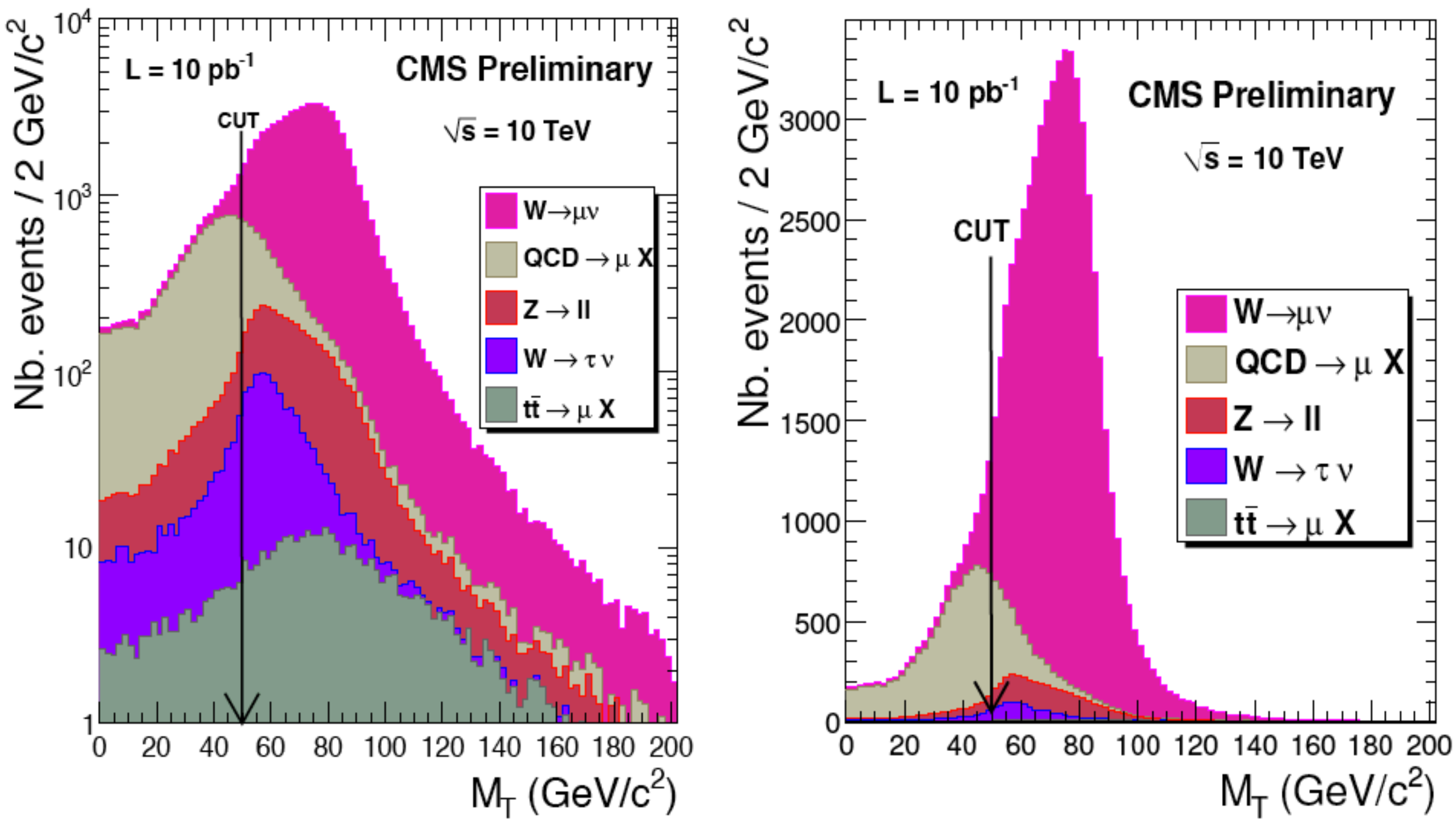
- Inclusive W or Z to e or μ cross-section measurements at CMS are grouped into e and μ channels.
- This allows common features of the analyses, e.g. e or μ selection & efficiencies, to share resources.
- In general the cross-sections are measured as:

$$\sigma_{W/Z} \times BR(W/Z \rightarrow \ell\nu/\ell^{+}\ell^{-}) = \frac{N_{W/Z}^{pass} - N_{W/Z}^{bkg}}{A_{W/Z}\varepsilon_{W/Z}\int Ldt}$$

- The proposed methods for measuring the various quantities for each decay mode in early data are presented in the following slides.

W → μν at 10 TeV

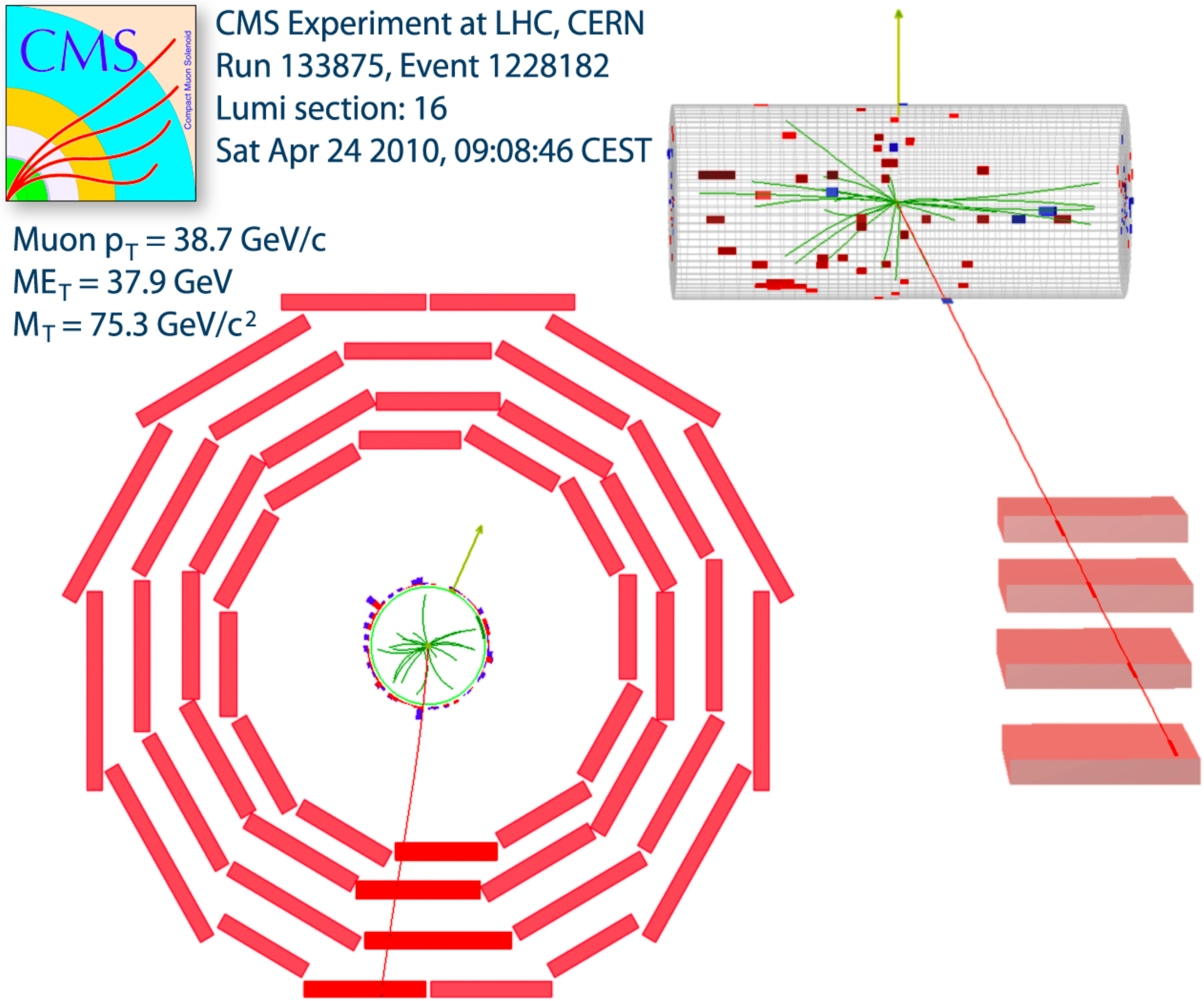
- Selection (from MC at 10TeV, cross-sections 30-40% less at 7TeV)
  - Single non-isolated muon trigger
  - Reconstructed muon with $p_T > 25$ GeV/c, $|\eta|<2.0$, isolated (relative sum $p_T <$ 0.09, cone $\Delta R < 0.3$).
  - Transverse mass cut $M_T > 50$ GeV/c^2



$W \to \mu\nu$ at 10 TeV

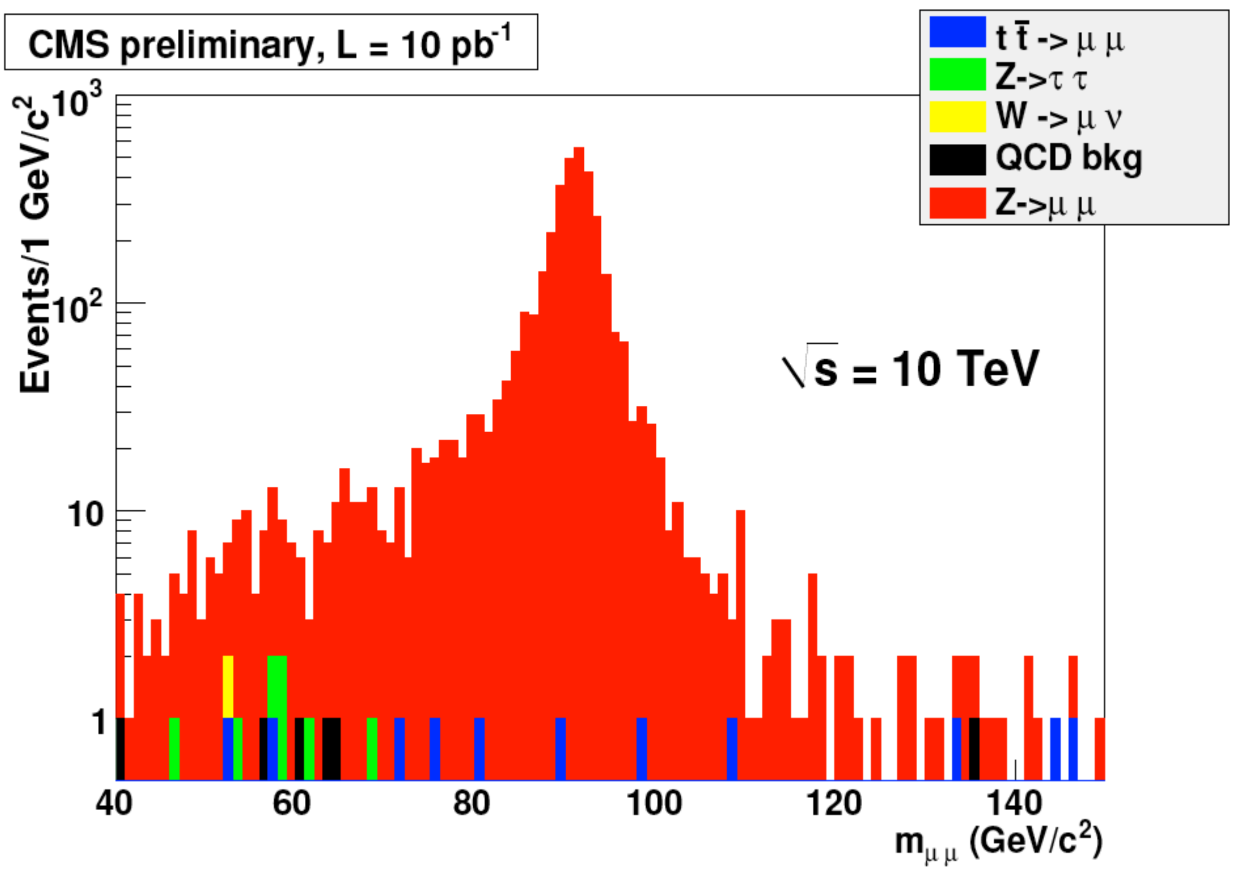
- Backgrounds: Pion & Kaon backgrounds suppressed (mostly low p_T), punch through negligible, most background from B hadron decays – QCD.
- Backgrounds will be estimated directly from data using two methods:
  - Matrix method: Divide M_T vs iso plane into four regions: (iso, M_T), (non-iso, M_T), (iso, non-M_T), & (non-iso, non-M_T). The no. of background events in the signal region can be extracted from a relationship between no. of background events in the four regions.
  - Template method: Signal template from $Z \to \mu\mu$ events with one muon dropped, background template from events with isolation criteria inverted. Use templates to fit data and subtract background.
- Muon efficiency will come from high purity $Z \to \mu^+\mu^-$ samples, and will be obtained using tag & probe techniques.

$W \rightarrow \mu\nu$ Event 7 TeV



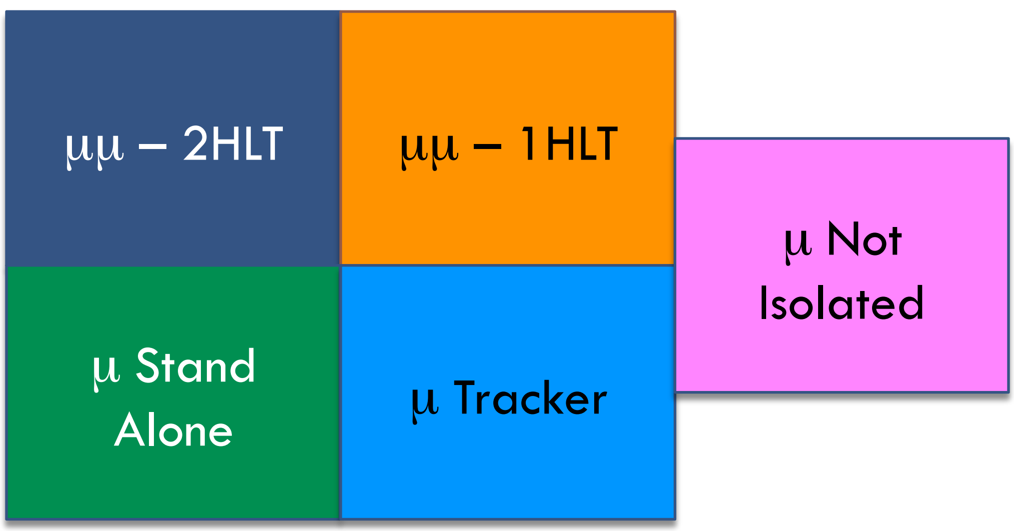
$Z \to \mu^+\mu^-$ at 10 TeV

- Selection (from MC at 10TeV, cross-sections ~50% less at 7TeV)
  - Single non-isolated muon trigger
  - Require two opposite sign muons with $p_T > 20$ GeV/c
  - One muon matched to high level trigger muon track that fired the event
  - Isolated (sum p_T all tracks in $\Delta R < 0.3$ must be < 3 GeV/c).

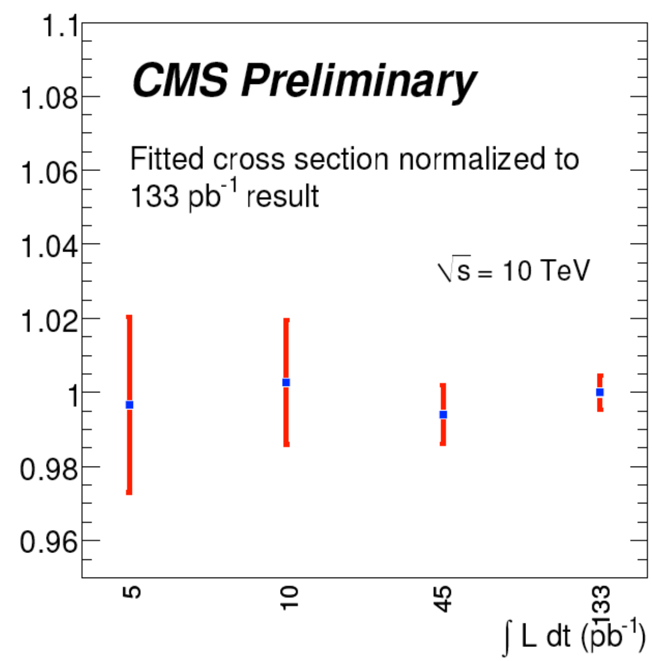


Z → $\mu^+\mu^-$ at 10 TeV

Define 5 **uncorrelated** categories of muon pairs. Fit the pairs simultaneously to determine signal yield and relevant efficiencies.

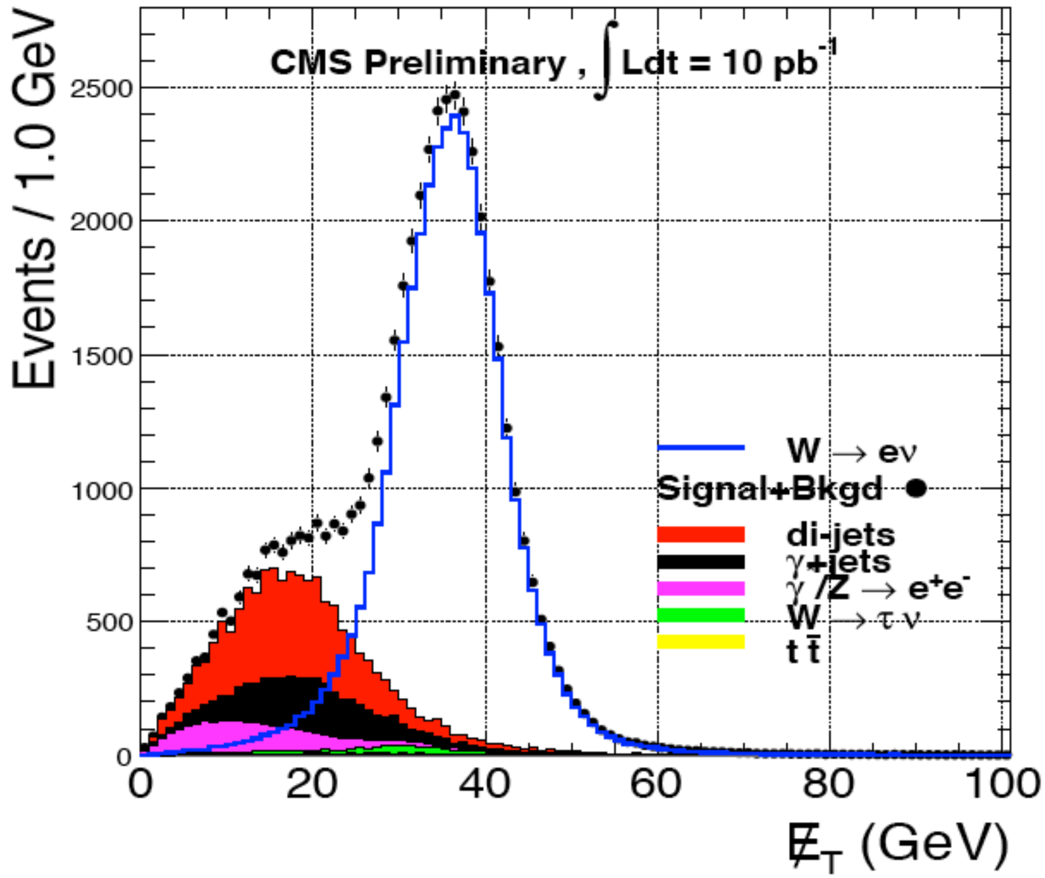


- When samples with large statistics are available reconstruction and trigger efficiencies may be determined using tag & probe techniques.
- For early data, when statistics is not large enough to bin efficiency in p_T & η, a simultaneous fitting method can be used.



W → eν at 10 TeV

- Selection (from MC at 10TeV, cross-sections 30-40% less at 7TeV)
  - Single electron trigger
  - Reconstructed electron: Association of high E_T supercluster in ECAL and a high p_T track. Require $E_T > 30$ GeV and $|\eta| < 2.5$ (fiducial region).
  - Isolation cuts applied, based on ΔR cone and trk, HCAL, ECAL, sum p_T
  - Additionally have electron shower shape cuts.

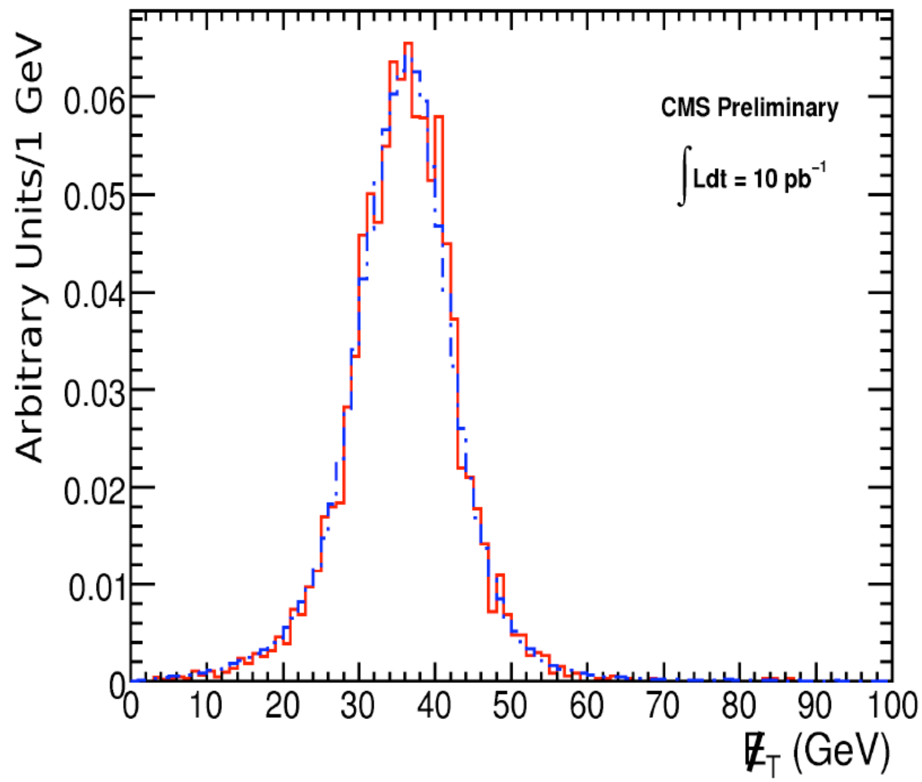


$W \rightarrow e\nu$ at 10 TeV

- Backgrounds: Some electroweak background from $Z \rightarrow ee$, can be estimated from simulation. Most background from QCD.
- Backgrounds estimated directly from:
  - Template method: Signal template from $Z \rightarrow ee$ events with one electron dropped, background template from events with isolation criteria inverted. Solve for number of signal events using an algebraic method.
- Electron efficiency will come from high purity $Z \rightarrow e^+e^-$ samples, and will be obtained using tag & probe techniques.

Template from Zee

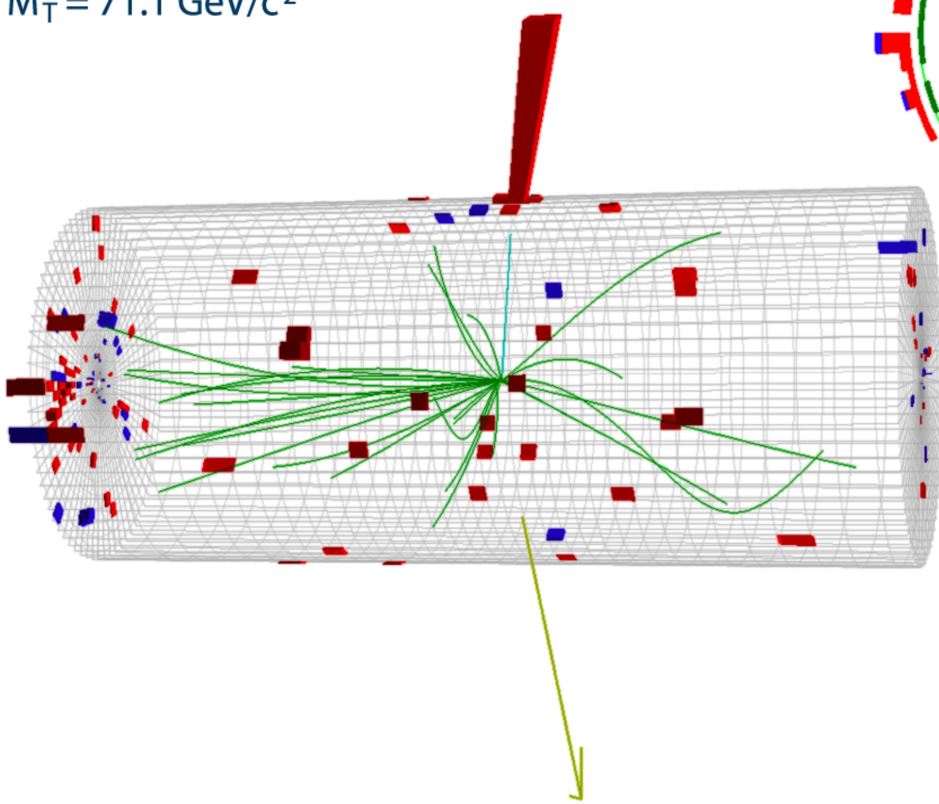
$W \rightarrow e\nu$ signal

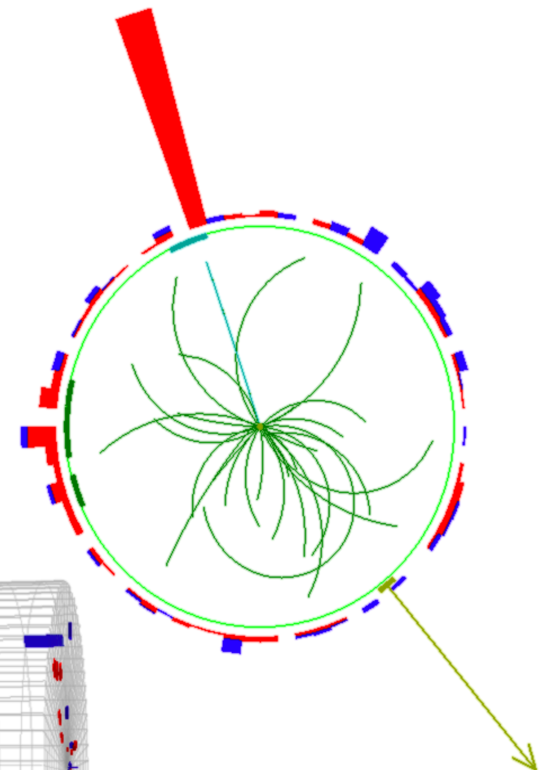


W → eν event at 7 TeV

CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST

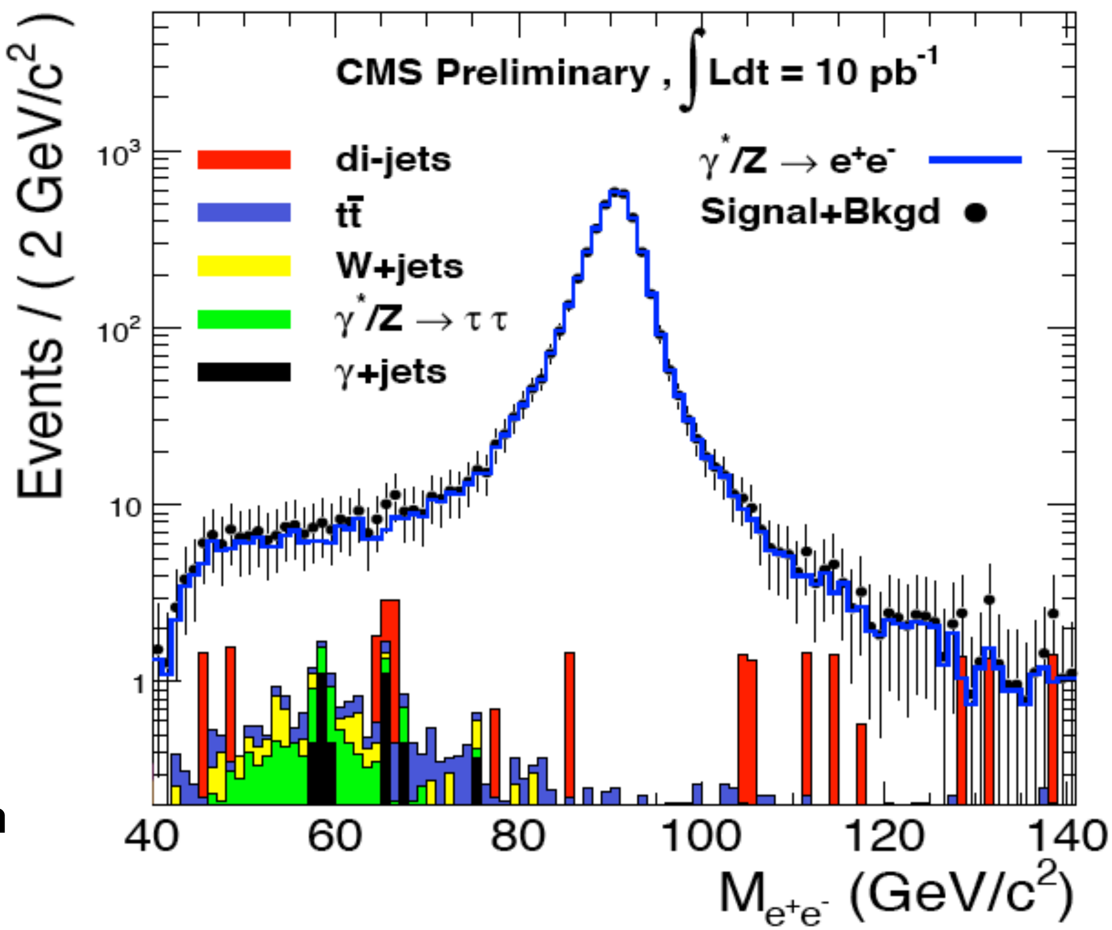
Electron $p_T = 35.6$ GeV/c
$ME_T = 36.9$ GeV
$M_T = 71.1$ GeV/c^2





$Z \to e^+e^-$ at 10 TeV

- Selection (from MC at 10TeV, cross-sections 30-40% less at 7TeV)
  - Single electron trigger
  - Two reconstructed electrons: Association of high E_T supercluster in ECAL and a high p_T track. Require both $E_T > 20$ GeV and $|\eta| < 2.5$ (fiducial region).
  - Isolation cuts applied, based on ΔR cone and trk, HCAL, ECAL, sum p_T (looser than for W)
  - Additionally have electron shower shape cuts.



Backgrounds very small: 0.35% of signal region $70 < M_{ee} < 110$ GeV/c^2

Z Differential Cross-Sections

- Measure Z → ee cross-section as a function of Z rapidity.
- Can provide constraints on parton distribution functions (PDFs) given sufficient statistics.

$$Y = \tfrac{1}{2}\ln\frac{E + p_z}{E - p_z}$$

$$\frac{1}{\sigma}\frac{d\sigma(Z \to ee)}{dY_i} = \frac{\varepsilon \times A}{N - B}\cdot\frac{N_i - B_i}{\Delta_i(\varepsilon \times A)_i}$$

N_i = Number of Z cands in data

B_i = Number of estimated background events

Δ_i = Bin width

$(\varepsilon \times A)_i$ = Efficiency time acceptance in bin i

Z Differential Cross-Sections

Selection

Loose isolation single e trigger

Z cand from e+e-: One electron track + supercluster + isolation.

One electron calo+trk or HF

50 (70) < M_{ee} < 150 (110) GeV/c^2

Isolation + shower shape

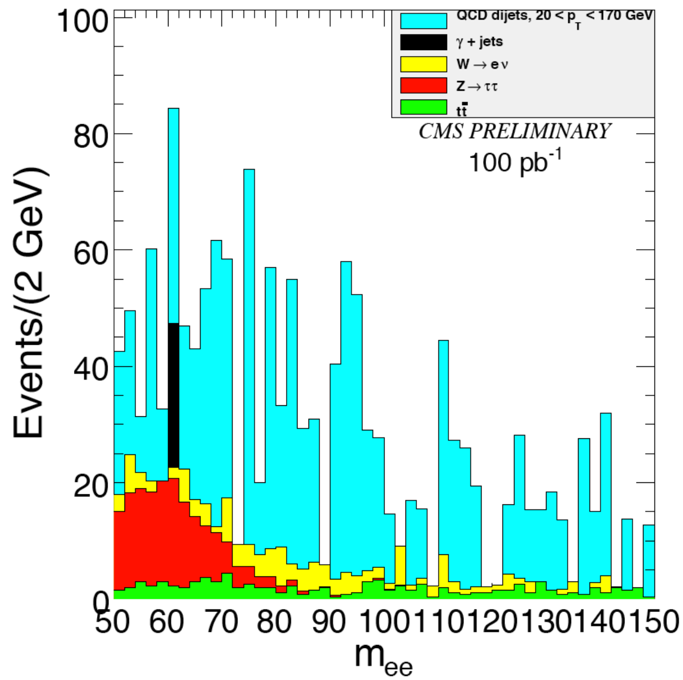
Efficiency & Acceptance

Efficiency from tag and probe

($\varepsilon \times A$) from measured effs applied to MC events smeared with a fast sim package tuned to Z peak data

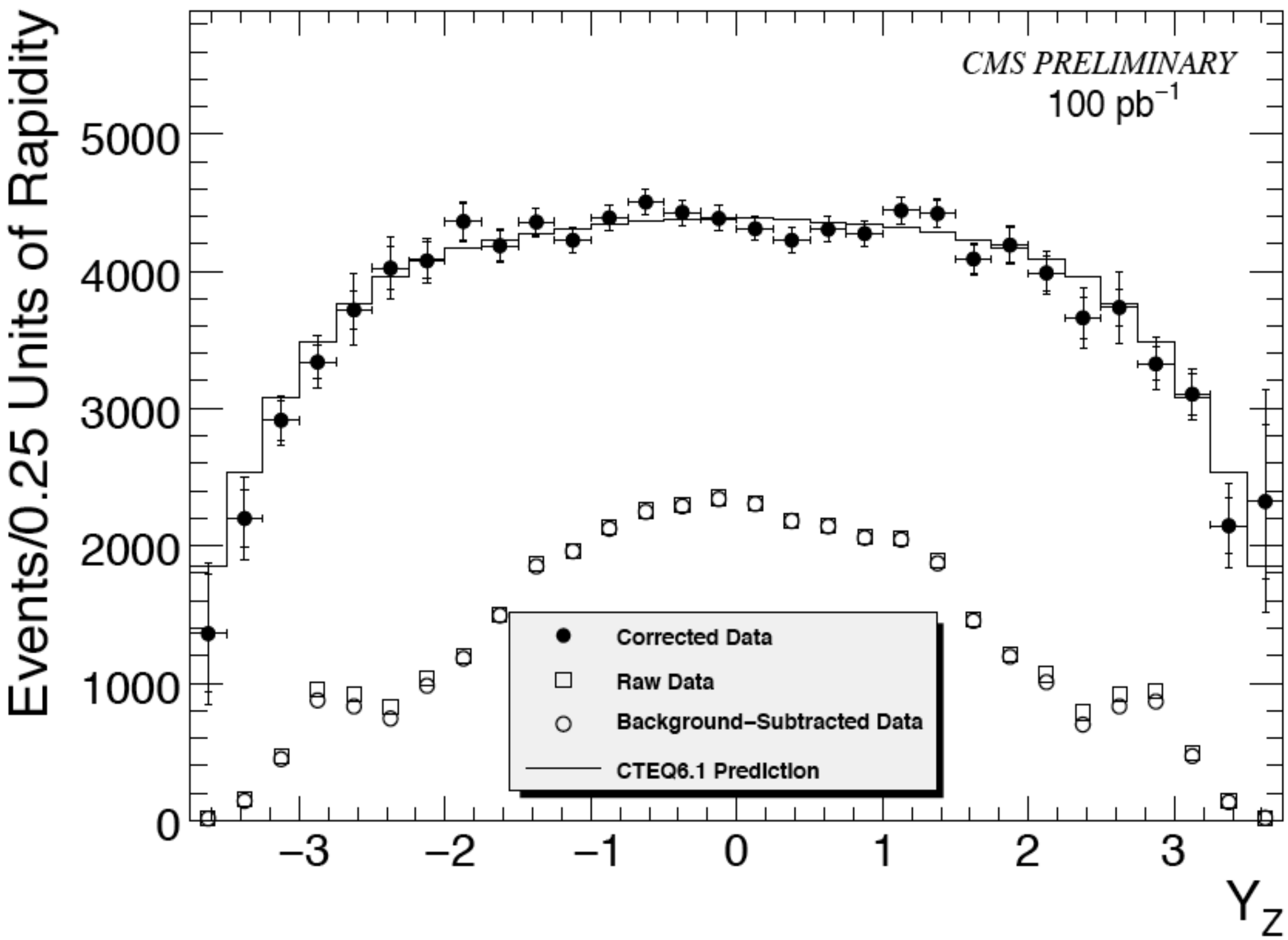
Background Subtraction

Assume e^+e^- mass from backgrnd is featureless in the signal region. Fit for the background subtraction with Voigtian (signal) + exp (background).



Z Differential Cross-Sections

- Results at 10 TeV with 100 pb^{-1} of data. Can see results with as little as 10pb^{-1}



W Charge Asymmetry

The process pp → W($\mu\nu$) + X has a large cross-section O(10nb) at 10 TeV. Differential cross-section in lepton pseudo-rapidity can be measured with $10pb^{-1}$ and the W muon charge asymmetry can be measured with <1% statistical error with $100pb^{-1}$ of data.

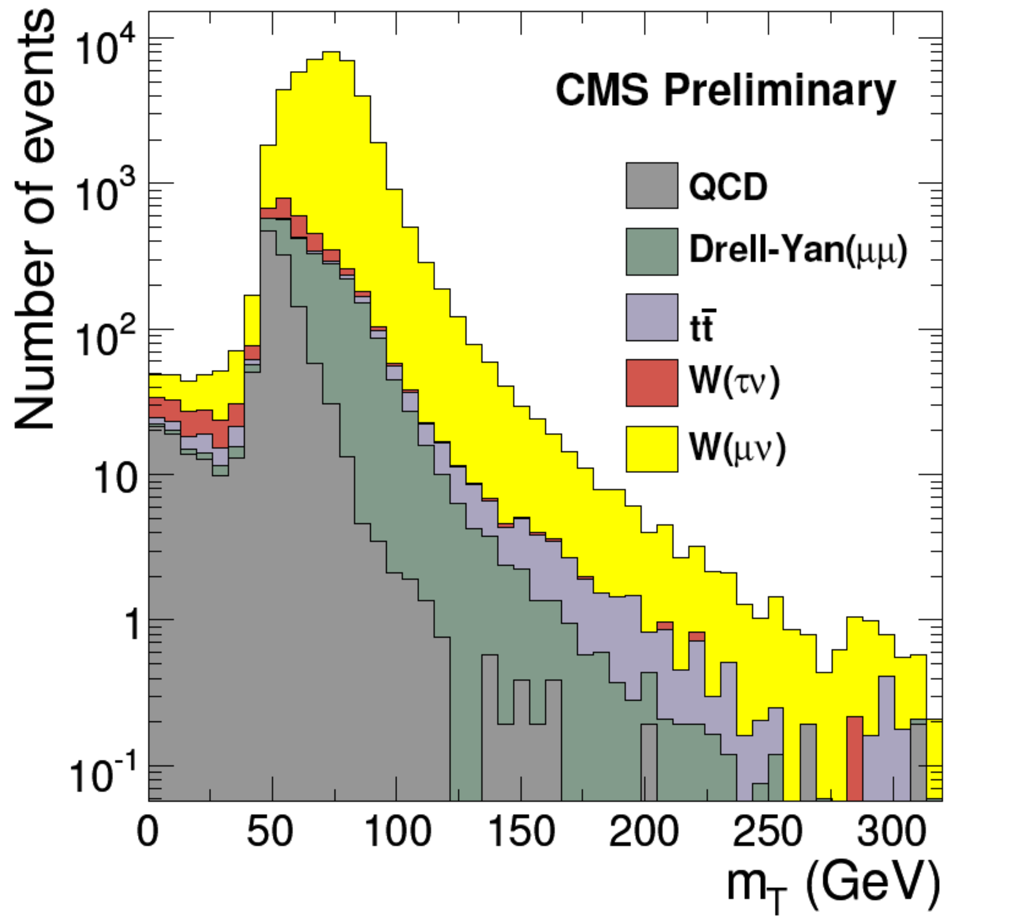
$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \rightarrow \mu^+\nu) - \frac{d\sigma}{d\eta}(W^- \rightarrow \mu^-\nu)}{\frac{d\sigma}{d\eta}(W^+ \rightarrow \mu^+\nu) + \frac{d\sigma}{d\eta}(W^- \rightarrow \mu^-\nu)}$$

The charge asymmetry is sensitive to the underlying parton distribution functions (PDFs) and can be used to distinguish different PDF calculations given enough statistics and control of systematic uncertainties.

W Charge Asymmetry

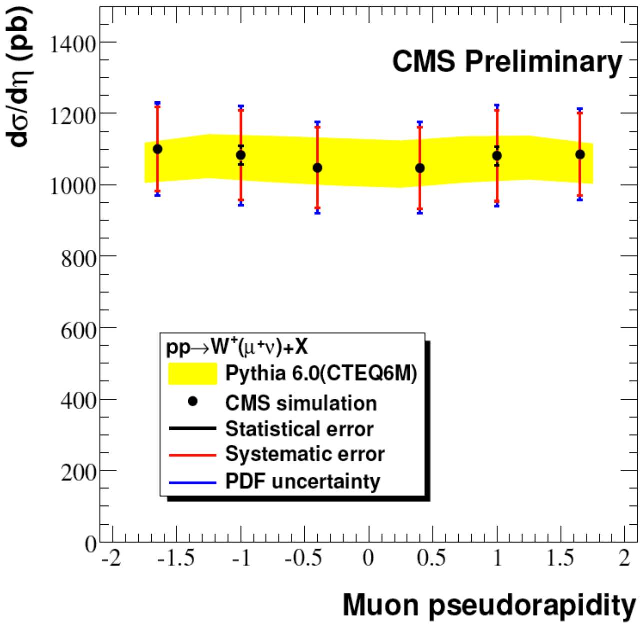
Selection

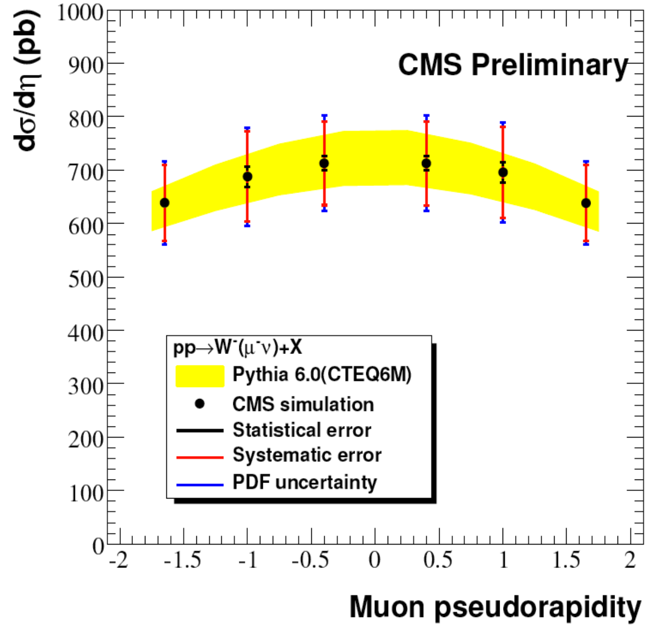
- Single muon HLT non-isolated
- HLT-matched muon ($|\eta|<2.1$)
- Muon $p_T > 25$ GeV/c
- Isolated: $1-p_T/(p_T+iso) < 0.05$
- MET > 20 GeV

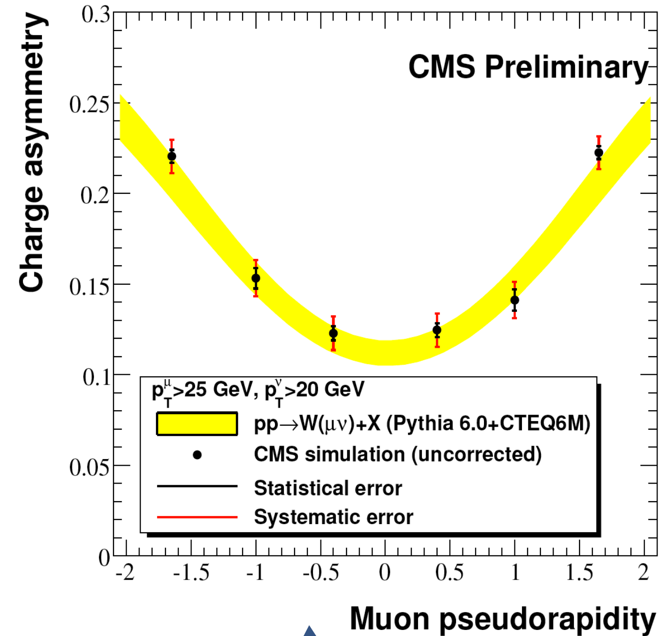


$$m_T = \sqrt{2 p_T MET(1-\cos(\Delta\phi))}$$

W Charge Asymmetry







Differential cross-sections with $10pb^{-1}$. W^+ left, W^- right.

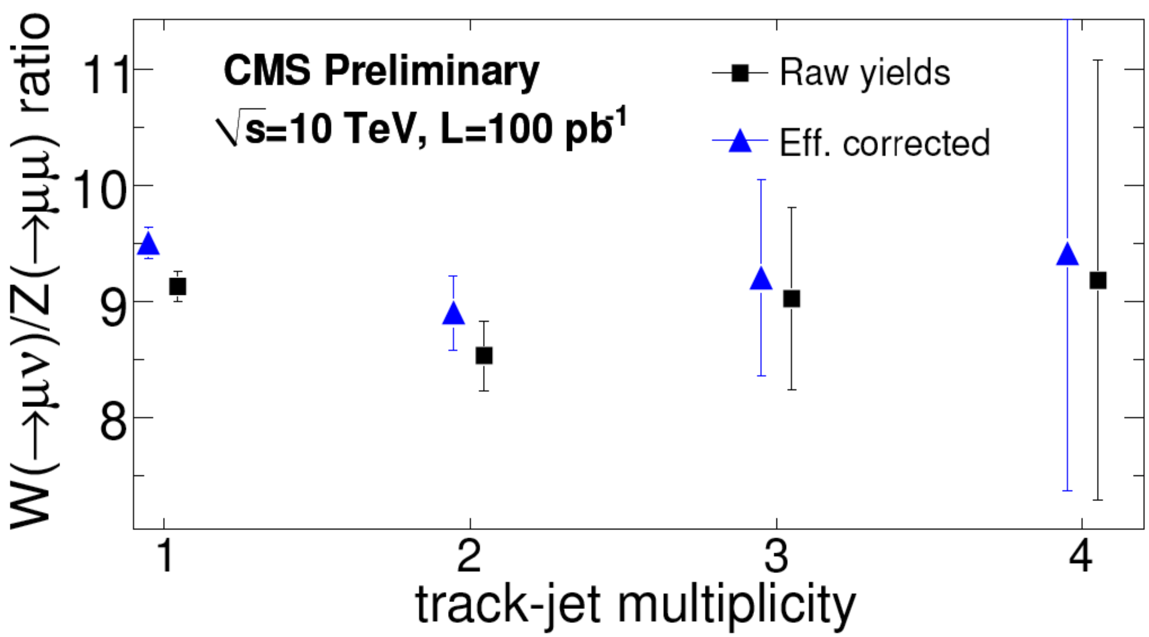
Charge asymmetry with $100pb^{-1}$. If errors are controlled PDF shapes can be probed.

W + jets to Z + jets Ratio

The double ratio, shown to the right, is predicted by QCD to be ~1 independent of jet multiplicity. With O(100pb^{-1}) of data this can be tested at CMS for up to 4 jets.

$$\frac{C_W}{C_Z} = \frac{W + n \text{ jets} / W + (n+1) \text{ jets}}{Z + n \text{ jets} / Z + (n+1) \text{ jets}}$$

Example CMS analysis with 100pb^{-1} at 10 TeV. Jets from track-jet algorithm. Different parts of phase-space are probed with calo-jet algorithm.



Jet Reconstruction

In early data detector understanding will be limited.

The SISCone algorithm is used to cluster either calorimeter deposits (calo-jets) or silicon tracks (track-jets).

Eventually can use particle-flow jets and corrected calo-jets.

Summary

- First observation of W & Z boson events with less than $10 nb^{-1}$ of 7 TeV data.
- First mass peak observations and cross-section measurements will be made with few pb^{-1} – for summer conferences.
- With $10 pb^{-1}$ can start to measure differential distributions.
- With $100 pb^{-1}$ can start to discern PDF shapes and measure associated Vector Boson + jet production.